II.3 Solid State Energy Conversion Alliance

Objectives

- Develop a 3-5 kW SOFC power system for a range of fuels and applications.
- Develop and demonstrate technology transfer efforts on a 3-10 kW stationary distributed power generation system that incorporates endothermic reforming of methane, and then natural gas.
- Initiate development of a 3-5 kW system for future mass-market transportation auxiliary power unit applications, incorporating endothermic reforming of diesel and gasoline.

Accomplishments

- Peak Power Performance-Delphi's SECA demonstration system produced peak power of 4.24 kW on methane, achieving the SECA Phase I goal of 3-10 kW.
- Peak Efficiency-Delphi's system demonstrated a peak efficiency of 37 percent, exceeding the SECA Phase 1 goal of 35 percent.
- Power Degradation-Delphi's demonstration system matched the SECA Phase I durability goal with power degradation of just 7 percent over 1,500 hours of operation.
- Factory Cost-Delphi met the SECA Phase I goal of $800.00 per kW by achieving an estimated $770 per kW.
- Successful fabrication, integration and testing of 30-cell stacks in the SECA Phase I demonstration system.
- Development of a capable reformer was substantially accomplished as the SECA demonstration system reformer design underwent significant systems level durability testing with minimal degradation.
- Delphi's BOP component hardware was fabricated and tested for SECA Phase I. With the commencement of system durability testing, BOP design efforts focused on supporting system hardware builds and maintaining hardware currently on system test. Supplier sourcing activity during this period included identifying future prototype and production suppliers for process air manifolds, and cast integrated component manifolds.

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Introduction

Delphi has been developing SOFC systems since 1999. After demonstrating its first generation SOFC power system in 2001, Delphi teamed with Battelle under the SECA program to improve the basic cell and stack technology, while Delphi developed the system integration, system packaging and assembly, heat exchanger, fuel reformer, and power conditioning and control electronics, along with other component technologies. Compared to its first-generation system in 2001, the Delphi-led team has reduced system volume and mass by 75 percent. By January 2005, the Delphi team was able to demonstrate test cells to DOE with power density more than required to meet the SECA 2011 goals.

In addition to its compactness, another key advantage of the SOFC is its high system fuel-efficiency, particularly when its high temperature co-product heat can be used in combination with its high electrical output. For example, SOFCs can be teamed with gas turbines driven by the SOFC's co-product heat to potentially generate power at 55 percent to 80 percent thermal efficiency (depending on scale and fuel used). This is significantly more efficient than today's typical coal-fueled power plant thermal efficiency of 35 percent to 40 percent. By co-generating power on-site at industrial facilities, commercial businesses, or even residences, the SOFC's high-grade co-product heat will enable up to 90 percent efficiency in distributed, combined heat and electrical power (CHP) generation. Similarly, heavy-duty trucks will be able to utilize SOFC auxiliary power systems for both heat and electrical power when parked, to save 85 percent of the fuel that today they consume when idling their main engine, and likewise reduce idling emissions.

While size and efficiency advantages are important for many potential applications, the SOFC's most significant advantage overall is its very broad applicability due to its inherent fuel-flexibility. With relatively small changes, SOFC systems can potentially operate on a full range of conventional and alternative fuels.

Approach

Delphi utilized a staged approach to develop a modular solid oxide fuel cell (SOFC) system for a range of fuels and applications including:

- Develop and test major subsystems and individual components as building blocks for applications in targeted markets.
- Integrate major subsystems and individual components into a "close-coupled" architecture for integrated bench testing.
- Integrate major subsystems and individual components into a stationary power unit (SPU) for the stationary market.
- Integrate major subsystems and individual components into an auxiliary power unit (APU) for the transportation market.

Results

To achieve the objectives of DOE/SECA Phase I, the Delphi effort focused on the performance testing and final system development to support Delphi's SECA Phase I demonstration tests. The SECA Phase I demonstration system was able to produce 4.2 kW net electric power output at greater than 35% fuel-to-electric system efficiency. The system met the 1,500 hour durability target including one full-thermal cycle at better than 99% operational availability. Delphi was also able to meet the cost target for Phase I of $800 per kW by achieving an estimated $770 per kW. All of these deliverables were achieved with a highly integrated system design weighing in at 85 kg (39 kg/kW), and with a package volume of 65 liters (30 liters/kW). Achieving these Phase I deliverables was the result of system design and integration efforts performed during Phase I, most notably:

- Delphi demonstrated cell power density in a 30-cell stack assembly of 700 mW/cm^2 at greater than 0.7 V/cell at operating conditions of 750°C nominal stack temperature, and simulated natural gas reformate fuel with greater than 60% utilization resulting in total power of 2.2 kW for the 30-cell stack. The complete stack assembly has a mass of 9 kg and volume of 2.5 liters for a mass specific power density of less than 4 kg/kW and volumetric power density of more than 0.9 kW/l.
- High efficiency fuel reforming strategy encompassing both internal reforming of methane gas in the SOFC stack and anode tail-gas recycle. This provided efficient thermal management of the SOFC stack, as well as effective fuel processing efficiencies which resulted in high system efficiencies.
- High reliability fuel reformer, SOFC stack, process air blower, electronic controller and electronic subsystems, sensors and actuators were developed. Delphi's dedication to integration and leverage of reliable automotive technology allowed for excellent durability performance.
- MATLAB/Simulink-based control software with rapid auto-code generation capability was utilized to enable a rapid software development process and the opportunity for many design iterations allowed for deployment and optimization of new technology in an efficient manner.

The SOFC system development effort during Phase I benefited from the experience and lessons-learned from several design generations of hardware. The current design is shown in Figures 1-3.

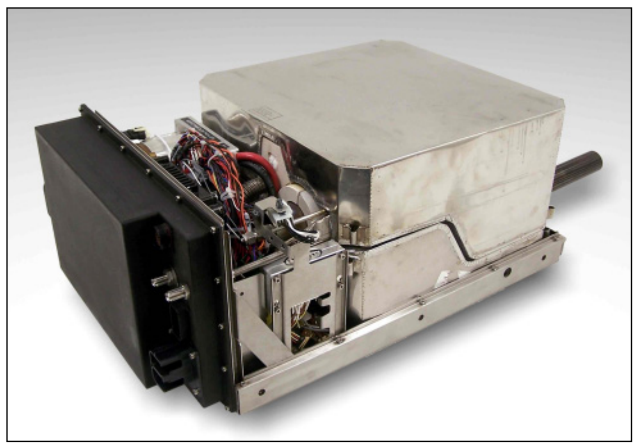

FIGURE 1. Delphi SOFC Uncovered with Insulation

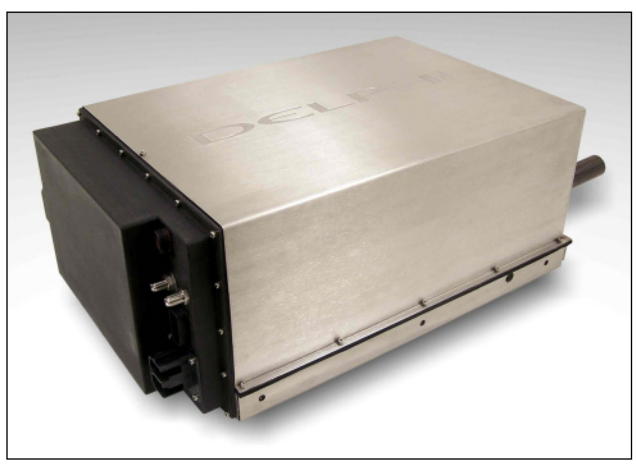

FIGURE 2. Delphi SOFC Covered Complete

One of the key achievements in stack development has been the successful fabrication and testing of 30-cell stack modules for integration into the system. The 30-cell stacks have produced power greater than 2 kW each. Figure 4 shows the Delphi 30-cell stack.

With the commencement of system durability testing, BOP engineering efforts focused on supporting system hardware builds and maintaining hardware currently on test. Supplier sourcing activity during this period included identifying future prototype and production suppliers for process air manifolds, cast integrated component manifolds, composite insulation shells, and a new generation mass air flow sensor. Coating tests for cathode heat exchangers were completed and resulted in the optimization of the Vapor Phase Aluminizing process at Delphi's coating supplier.

A multi-point fuel delivery system for gaseous fuels was refined and produced in small quantities in order to execute system level testing. Further development of the endothermic reformer was carried out resulting in initial recycle-based reforming performance that met system requirements.

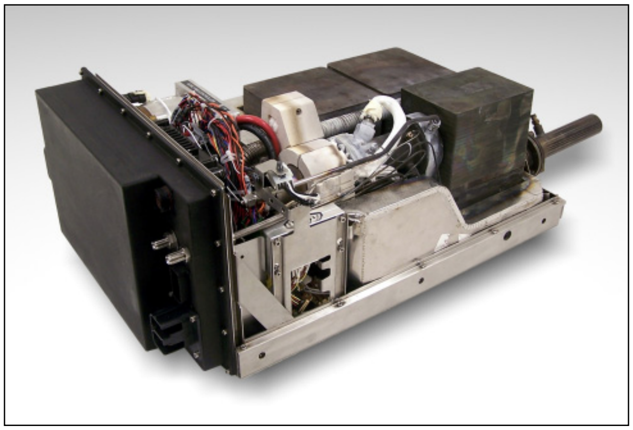

FIGURE 3. Delphi SOFC Uncovered with Application Interface Module

FIGURE 4. Delphi 30 Cell Stack

Conclusions and Future Directions

- Phase I SECA objectives have been met for power rating, efficiency, durability and cost.
- Improvements to reformer substrate and washcoat thermal stability permitted rigorous durability tests to surpass 2,500 hours of operation.
- Develop capability to operate using pipeline natural gas with fuel desulfurizer.
- Work on Phase II SECA requirements has begun.
- Continue materials development for improving cells, interconnects and seals.
- Continue work on increasing durability and capability to withstand more thermal cycles.
- Ultimately, the SECA Phase III goals are to deliver an SOFC power system capable of 40 percent or greater efficiency at a factory cost of $400 per kilowatt.

Special Recognitions & Awards/Patents Issued

1. Patents issued: The US Patent Office Grant Numbers: 7008709, 7025903, 6984466, 6974646, 7001682, 1376725, 6967064, 7008715, 6989211, 1387427, 7001685, 7008716

FY 2006 Publications/Presentations

1. November 2005: 2005 Fuel Cell Seminar in Palm Springs, CA., SOFC Stack and System Development: Latest Results, Steven Shaffer, Dr. Subhasish Mukerjee, Sean Kelly, Delphi Corporation.